“Hello, Quantum World”

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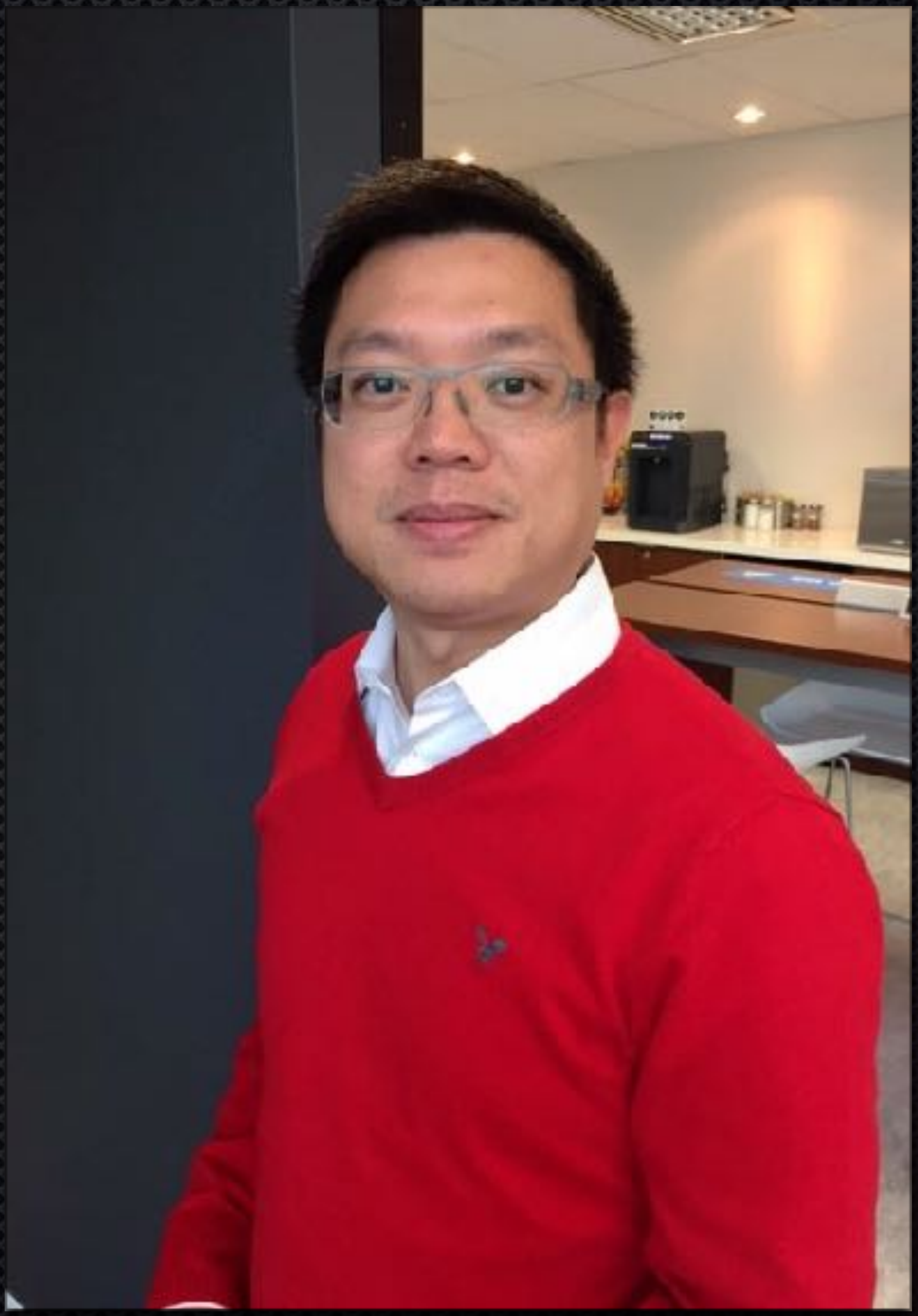
About Me

- Toronto - 20yrs+
- Trekkies
- Travel - for Food
- Research, Experiment, Development - Data



Premise

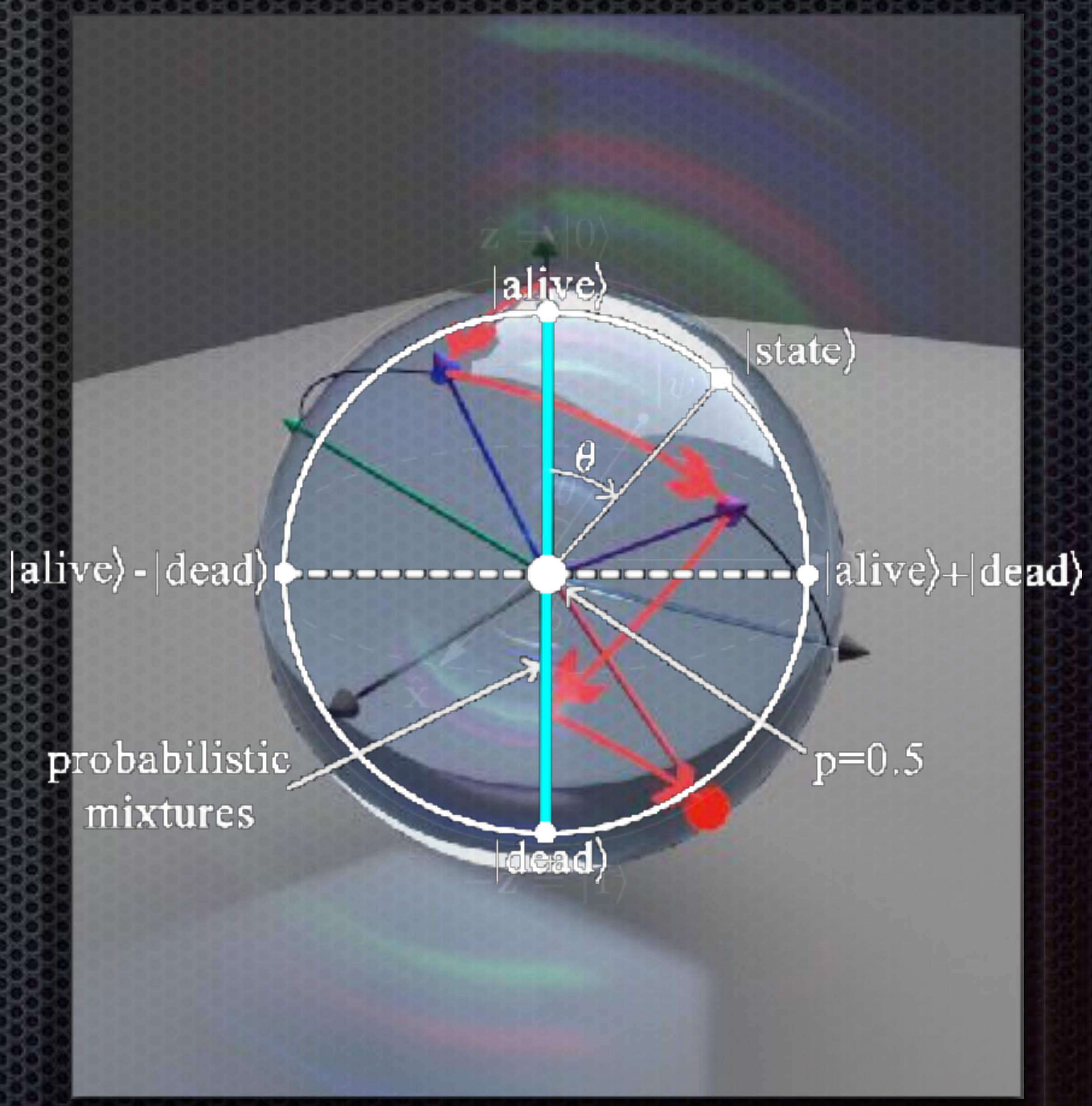
- Different places at the same time
- Different states at the same time

Analog

Classical	**Quantum**
Computer	Physical System
Computation	Motion
Input (Bits)	Initial State of the **Qubits**
Rules	Law of Motion
Output (Bits)	Final State of the **Qubits**
println()	Measure

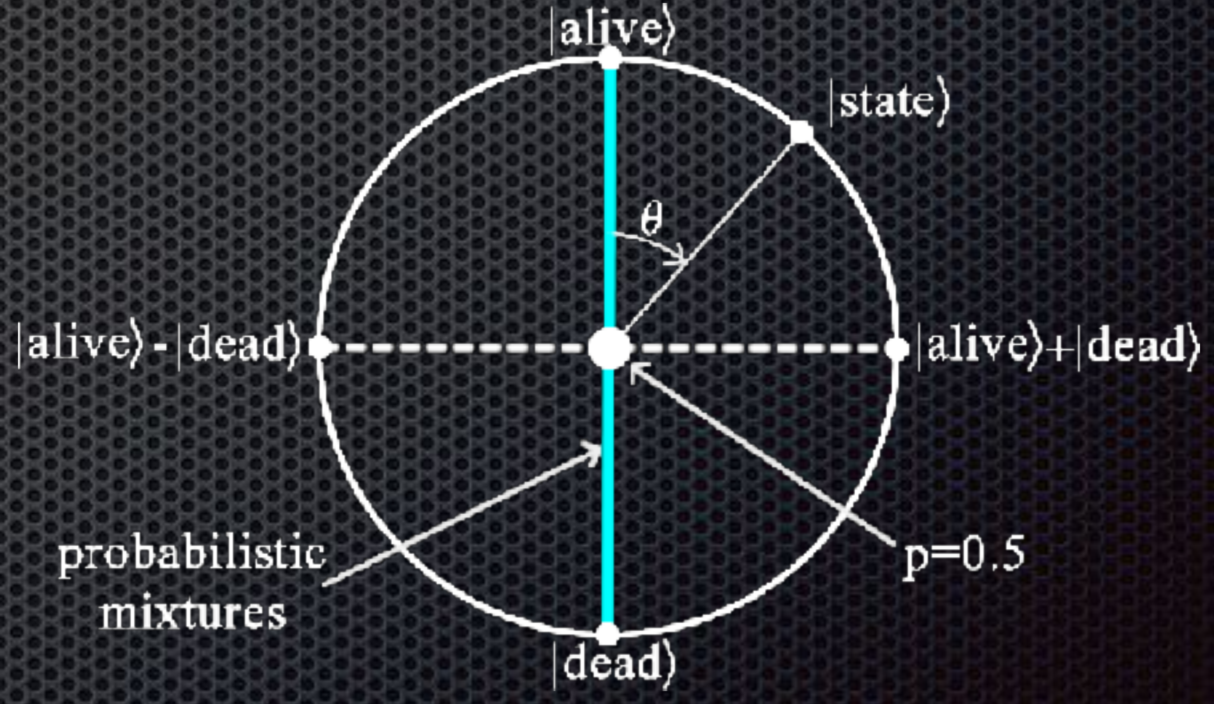
Qubit

- Qubit - quantum version of a bit
- Simplest quantum system with 2 states - can be in both states at the same time
- Represented by Bloch Sphere
- Qubits can be the observables for quantum objects like photons, electrons, atoms…etc



Superposition

- Superposition can achieved by a quantum gate called "**Hadamard**" Gate



- $H(|0>) = 1/\sqrt{2} (|0> + |1>)$
- $H(|1>) = 1/\sqrt{2} (|0> - |1>)$

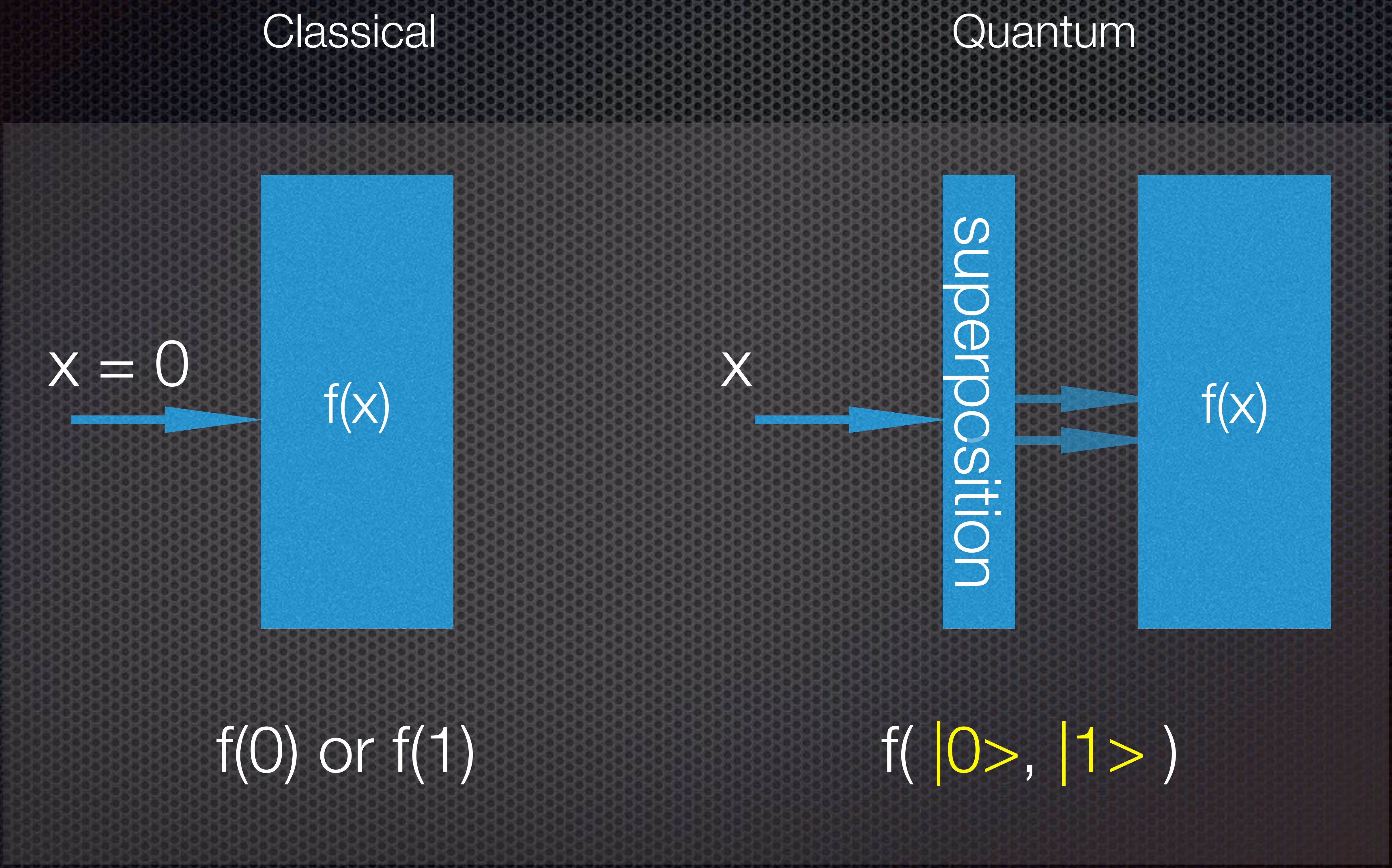
The power of coming together

- Bundle the qubits together and you’ve got a quantum computer
- Classical bits can only represent 1 value at one time
- Qubits can actualize 2^n values at the same time!

- 1 Qubit has 2 states = { |0>, |1> }
- 2 Qubits has 4 states = { |00>, |01>, |10>, |11> }
  - Superposition for 2 qubits will be the linear combination of both, example:
  - H(|0>)H(1>) = 1/√2 (|0> + |1>) 1/√2 (|0> - |1>)
    = 1/2 (|00> - |01> + |10> - |11>)
- 3 Qubits has 8 states = { |000>, |001>, |010>, |011>, |100>, |101>, |110>, |111> }
- n Qubits has 2^n states - express as the tensor product of the qubits

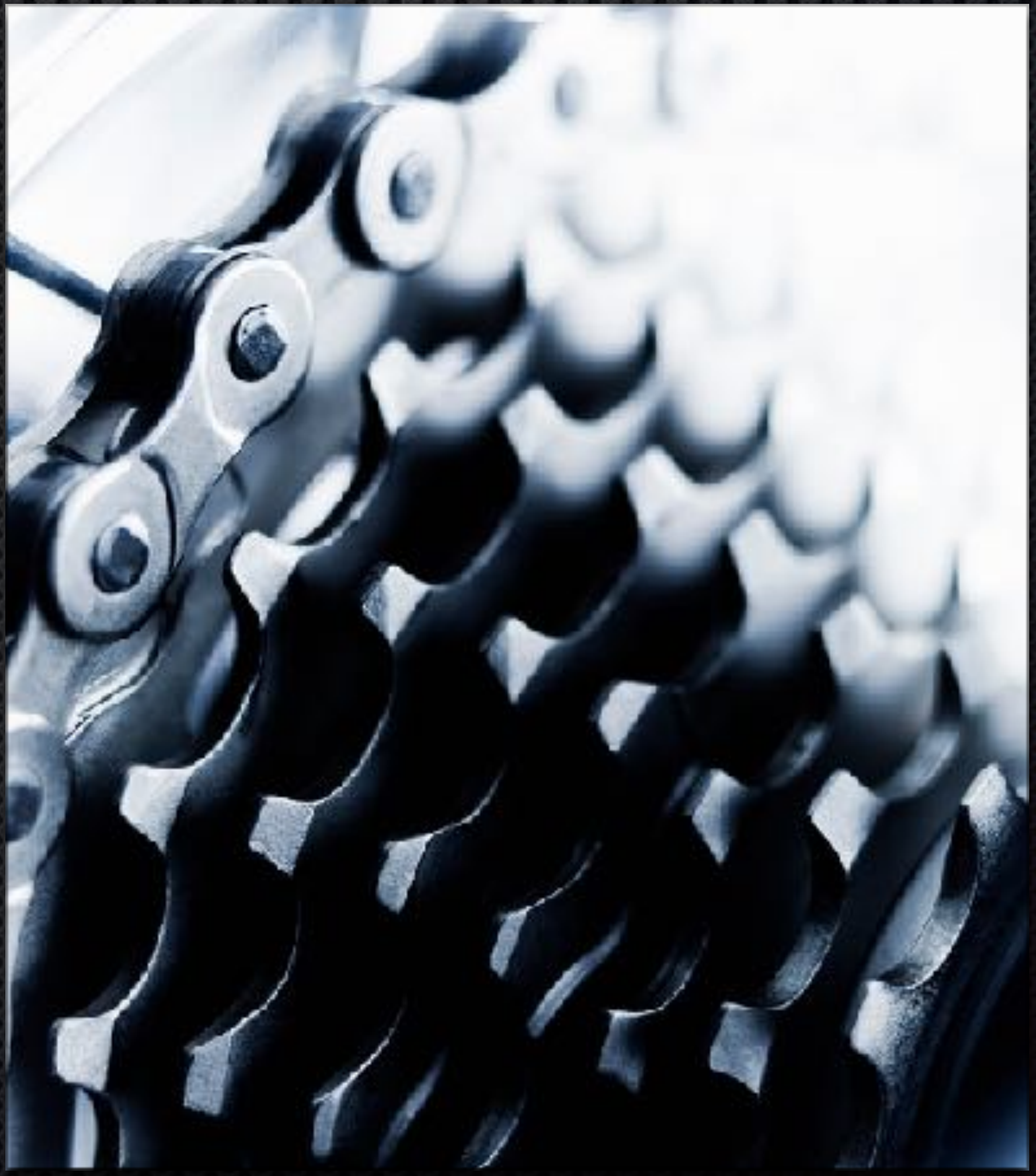
$$|A\rangle \otimes |B\rangle = \begin{bmatrix}\alpha_0\\ \alpha_1\end{bmatrix} \otimes \begin{bmatrix}\beta_0\\ \beta_1\end{bmatrix} = \begin{bmatrix}\alpha_0\beta_0\\ \alpha_0\beta_1\\ \alpha_1\beta_0\\ \alpha_1\beta_1\end{bmatrix}$$

Quantum Parallelism



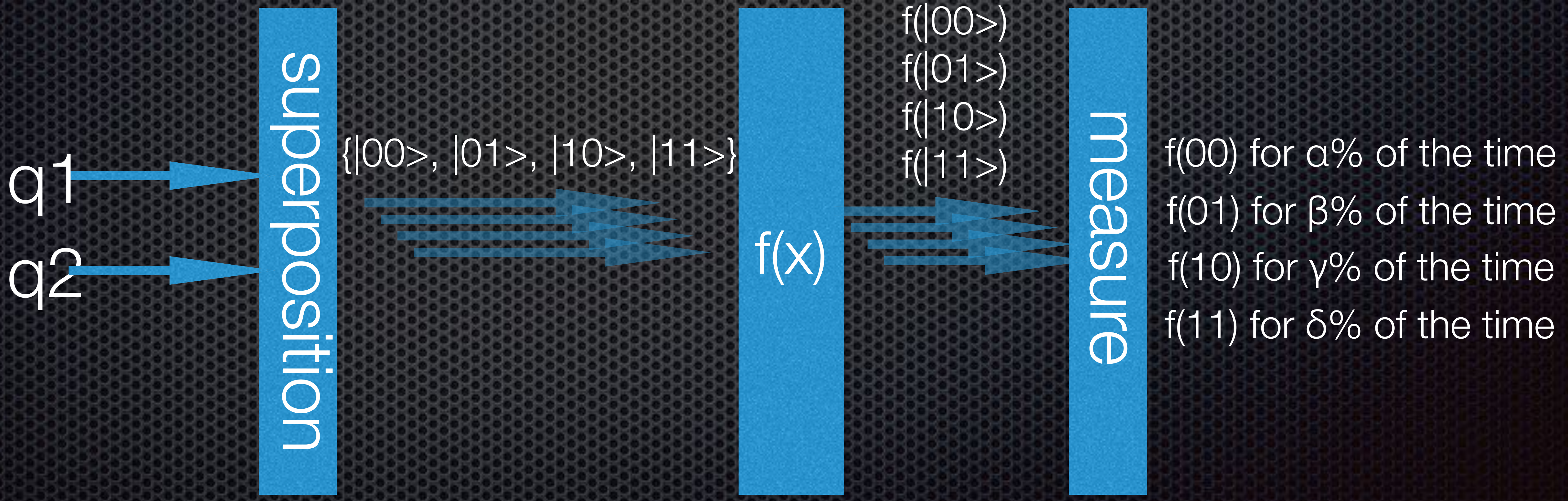
What is it good for then?

- *Acting on all Realities at once!*



One Little Detail

- Attempt to measure the state of the system will collapse the superposition and result in 1 of 4 possible answer
- Sharp —superposition—> Unsharp —measure—>Sharp



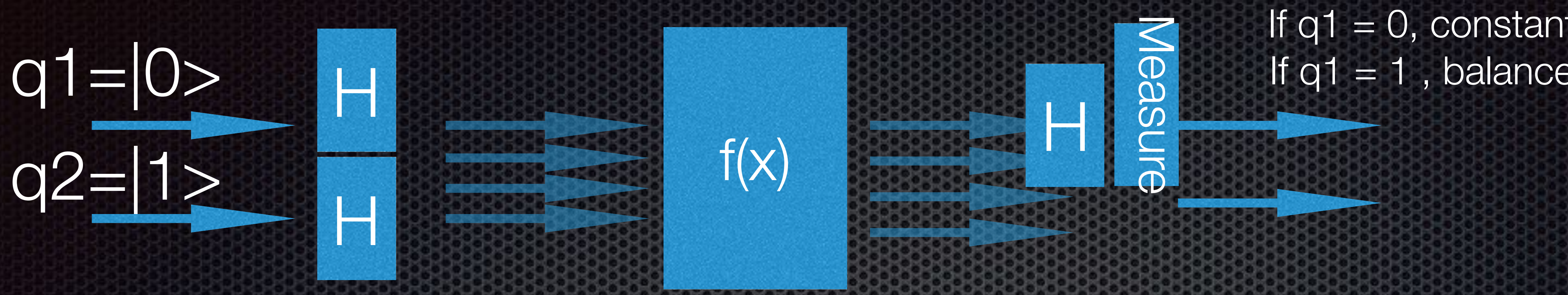
Example - Deutsch’s Algorithm

- **Puzzle**:- given binary f : {0,1} -> {0,1}, determine if it is a constant function or balanced function.
- Constant - all output are 1s or 0s
  Doesn’t depend on input
- Balanced - half the time 0 and half the time 1
  Depends on input

Binary function : f(x) has four possibilities

Input	1st f(x) always 0	2nd f(x) always 1	3rd NOT	4th COPY
0	0	1	1	0
1	0	1	0	1

- Need 2 tries for classical computers
- Using superpositions (quantum parallelism), determine in 1 try!

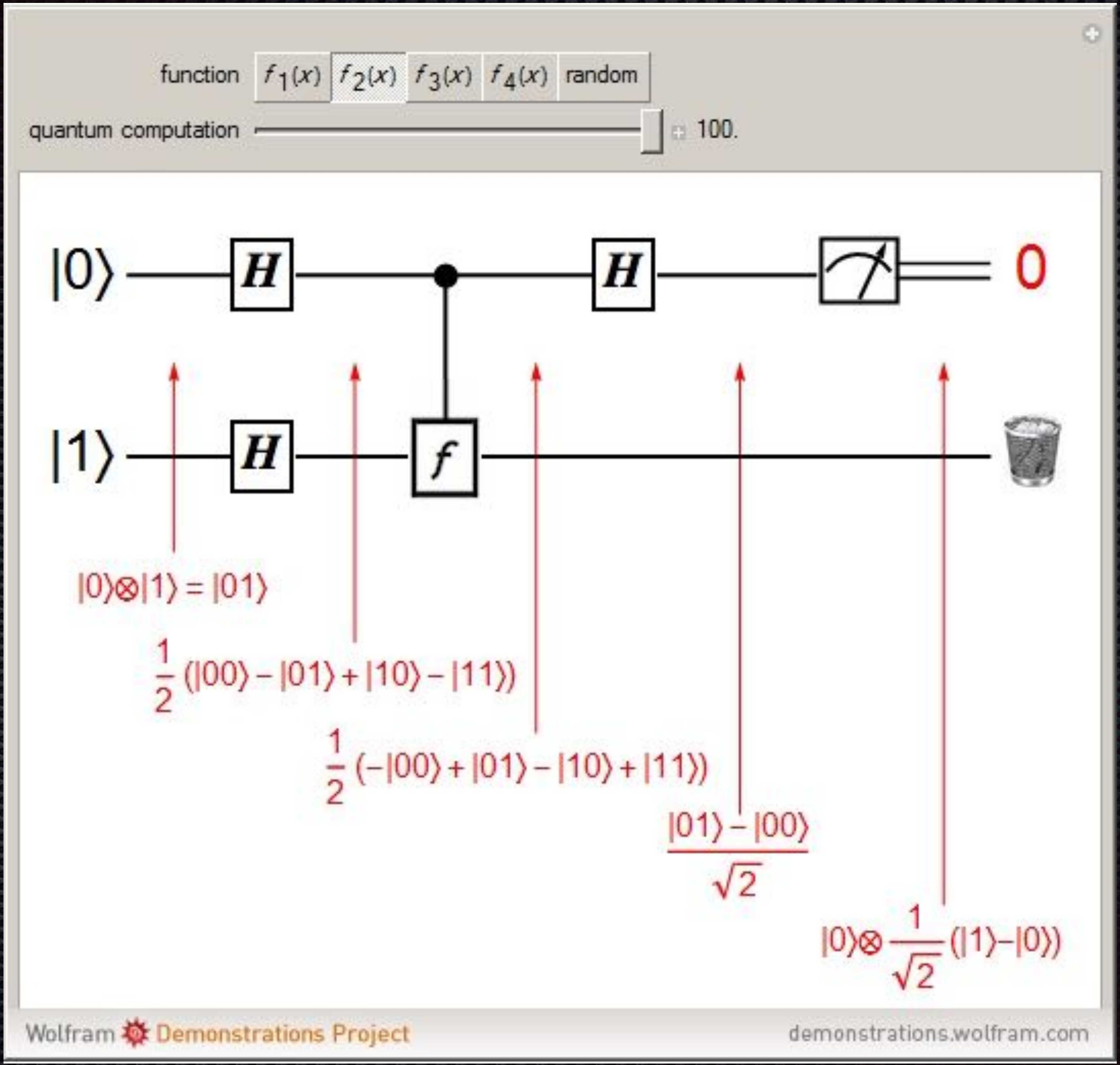


q1=|1>

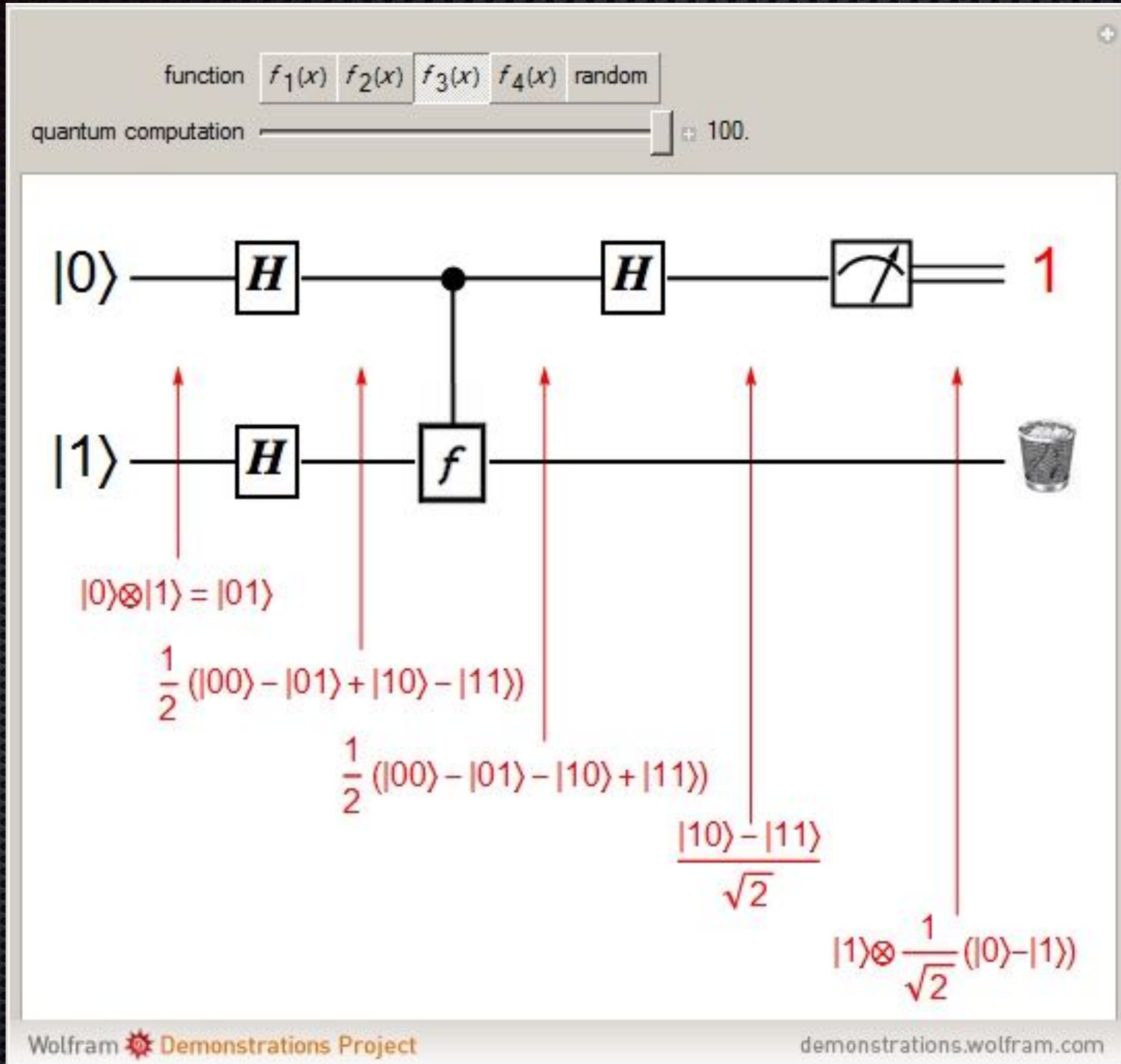
q2=|1>

	|q2,q1>			f(|q2,q1>)
+	0	0	+ -	f(|00>)
-	1	0	+ -	f(|10>)
+	0	1	+ -	f(|01>)
-	1	1	+ −	f(|11>)

$f(x) = 1$


function
f1(x) f2(x) f3(x) f4(x) random
quantum computation
100.
|0⟩
|1⟩
H
H
f
H
0
|0⟩⊗|1⟩ = |01⟩
1/2 (|00⟩ − |01⟩ + |10⟩ − |11⟩)
1/2 (−|00⟩ + |01⟩ − |10⟩ + |11⟩)
(|01⟩ − |00⟩)/√2
|0⟩⊗ 1/√2 (|1⟩−|0⟩)
Wolfram Demonstrations Project
demonstrations.wolfram.com

$f(x) = x$


function
$f_1(x)$
$f_2(x)$
$f_3(x)$
$f_4(x)$
random
quantum computation
100.
$|0\rangle$
$|1\rangle$
H
H
f
H
1
$|0\rangle \otimes |1\rangle = |01\rangle$
$\frac{1}{2}(|00\rangle - |01\rangle + |10\rangle - |11\rangle)$
$\frac{1}{2}(|00\rangle - |01\rangle - |10\rangle + |11\rangle)$
$\frac{|10\rangle - |11\rangle}{\sqrt{2}}$
$|1\rangle \otimes \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle)$
Wolfram Demonstrations Project
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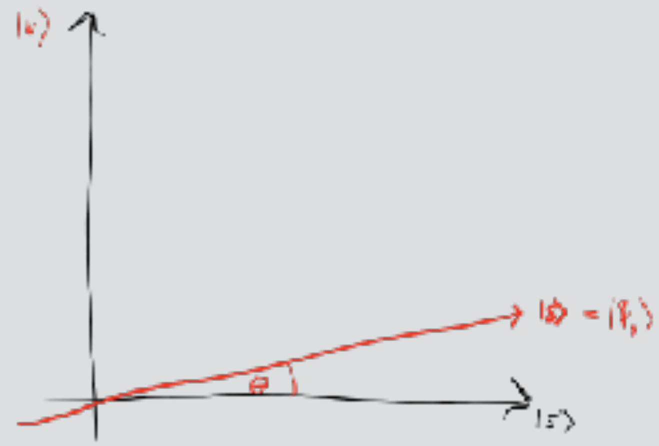
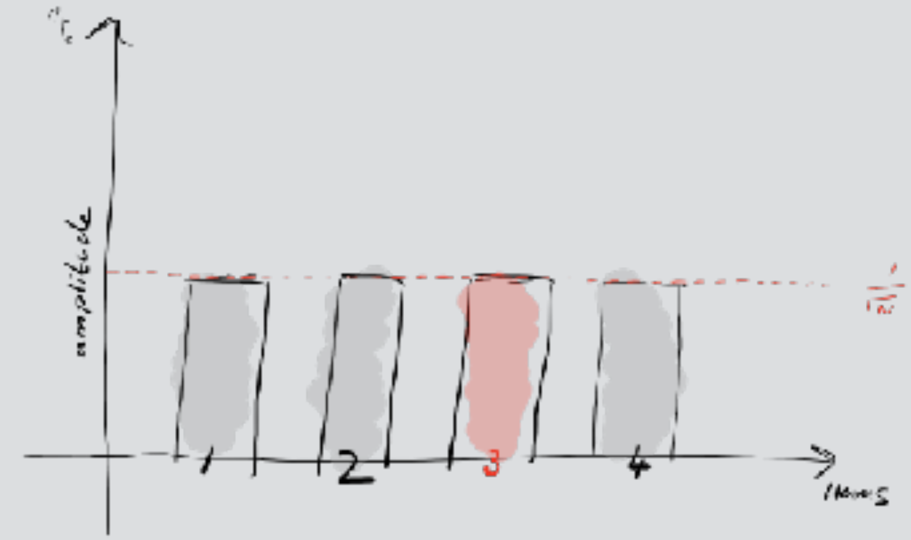
Example - Grover's Algorithm

- **Puzzle**:- given N keys, find the right key to the door
- Formal definition, X = {x1, x2,… xn}, f: X -> {0,1}, find x* so that f(x*) = 1
- Classical algorithm needs average N/2 tries
- Using quantum parallelism, only requires √ N times - quadratic speed up
- Encode using L Qubits where 2^{L} = N

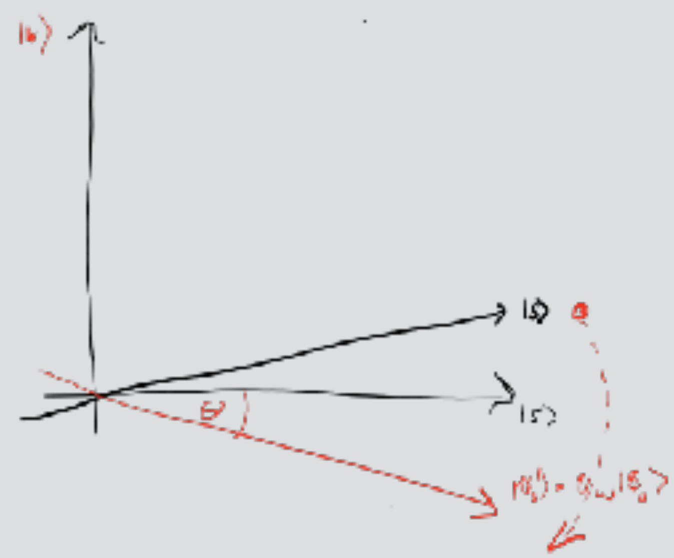
Superposition

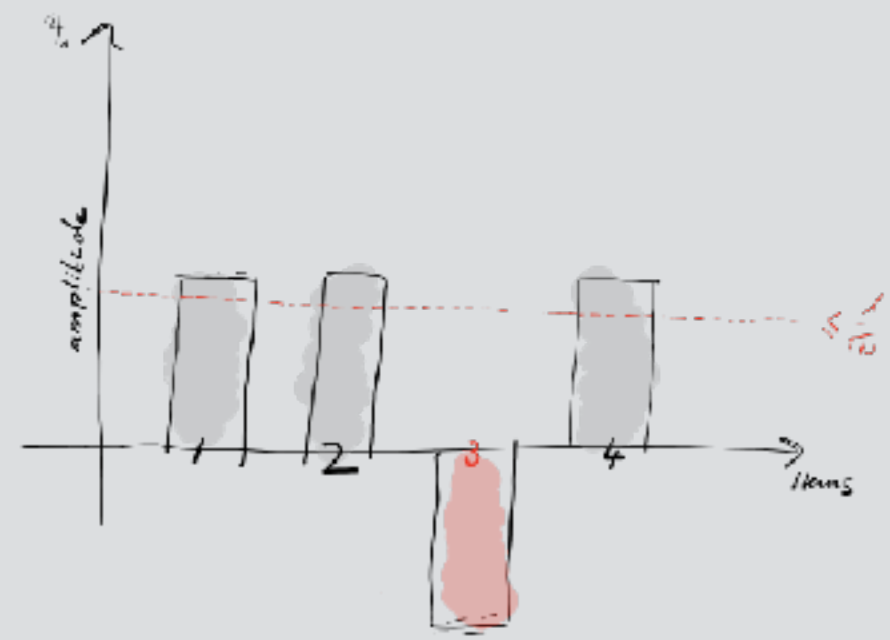




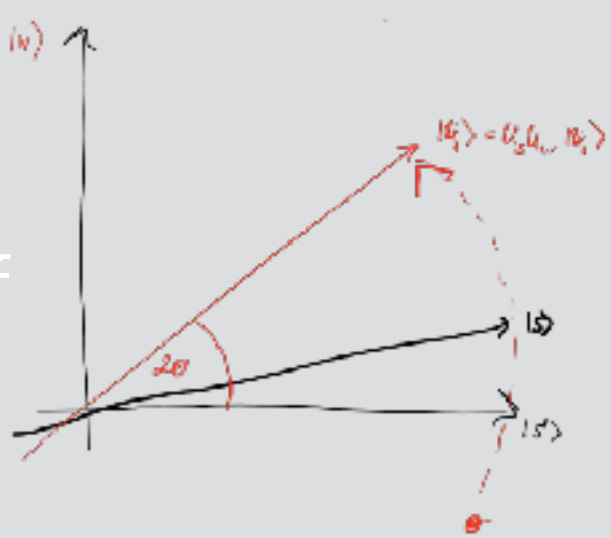
f(x*) to flip

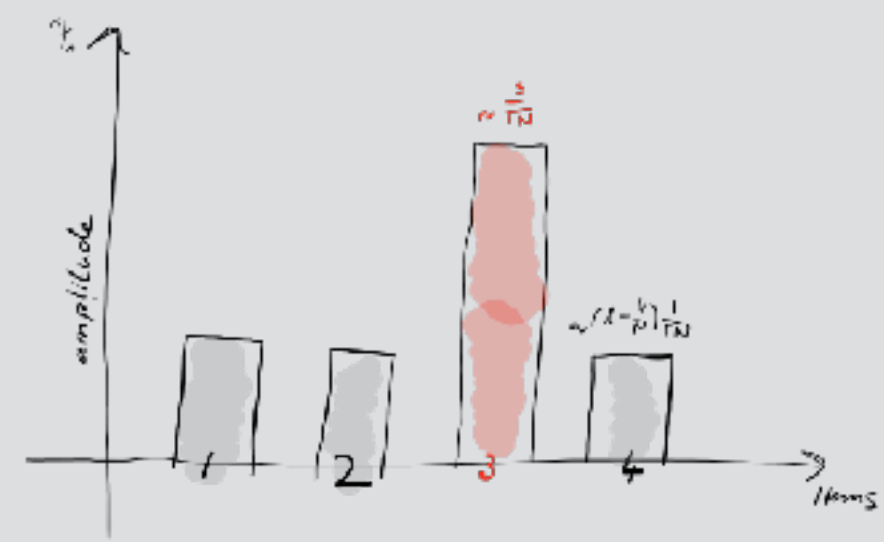
√ N





Increase Amplitude of x*





They are here!

- So far, simulation to help us learn
- There are companies currently implementing quantum computers such as:
    - D-Wave - 512 qubits
    - IBM Q - Public experimental playground 12 qubits

Applications

- AI & ML - optimization, linear equations…etc
- Biochemistry - protein folding using simulation
- Security - Quantum Key distribution

https://github.com/sansomlee/quantum.git